The impact of fracking activities on Oklahoma's housing prices: a panel cointegration analysis

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ABSTRACT

Fracking drilling has opened a discussion on the role of technological developments in economies engaged in shale oil and gas formations. Oil and natural gas production opened new possibilities for employment benefits and housing prices decreases. This paper explores, for the first time, the impact of fracking on housing prices across Oklahoma’s counties, spanning the period 2000-2015. Through panel methods, the findings show a positive effect on housing prices, while this positive effect gains statistical significance only over the period after the 2006 fracking boom. The results survive a robustness check that explicitly considers distance and groundwater-dependency issues.

Keywords: fracking (horizontal) drilling; housing prices; panel data; Oklahoma counties

JEL Classification: Q33, R00, C33

1. Introduction

As of September 2016, a backlash against fracking (i.e. horizontal drilling) in Oklahoma got worse following record-tying earthquakes. The numbers of earthquakes have been a far cry from the recent past, before the state’s fracking boom. As oil production surged in Oklahoma, so did the disposal of wastewater from fracked fields. Producers, and now the U.S. Environmental Protection Agency, have been facing lawsuits because of seismic activity allegedly linked to disposal wells in Oklahoma (as well as in other states) (Skoumal et al., 2015).

Oklahoma, a region previously not known for intense seismic activity, began having a significant number of earthquakes in 2006, the same year local oil companies began using fracking to shatter deep rock layers to extract oil and gas. Fracked wells produce large quantities of wastewater, which drilling companies inject into ultradeep disposal wells. The Oklahoma Corporation Commission, which regulates oil and gas activity in the state, has been issuing restrictions for more than a year aimed at cutting down on the amount of wastewater injected into disposal wells. Oklahoma is one of the major contributors of oil and gas in the U.S. This state has been selected in this study for its long history of oil and gas production. Over the period 1982 to 2013, Oklahoma comes in third position in terms of production, while the state is one of the leading states in terms of the number of gas wells drilled, only behind Ohio, Pennsylvania, West Virginia and Texas (U.S. Energy Information Administration. 2015).

At the same time, the fracking methodology can be seen as a major technological innovation in a particular sector. In theoretical terms, there has been a large strand of literature that debates whether technological innovations play a central role in asset pricing. However, standard empirical measures of technology shocks (e.g., Solow residuals) do not appear to explain observed movements in asset prices (for a overall discussion on the theoretical links between technological innovations and asset prices see the papers by Cochrane, 2011; Bansal et al., 2014; Greenwood and Shleifer, 2014; Greenwald et al., 2014; Albuquerque et al. 2015; Baker et al., 2015; Campbell et al., 2016). In terms of fracking drilling activities, the literature has primarily focused to explore whether innovations in shale technology affect corporate earnings and hence the stock returns in those firms that are directly or indirectly affected by those innovations (Lamont and Frazzini, 2007; Savor and Wilson, 2013, 2015; Lucca and Moench, 2015). To the best of our knowledge, no study has investigated the impact of those activities on housing assets.

At the same time, others have investigated whether the economic impact of fracking activities impact the real economy through employment, investments and housing (Hausman and Kellogg, 2015; Feyrer et al., 2017). The economy's sensitivity to fracking news can arise through several types of spillovers. To the extent that an increase in fracking/drilling activity increases the demand for output of industries that provide labor or materials for drilling oil extraction, the positive news about drilling sector productivity is good news for these industries, i.e. the "supply-chain effect" hypothesis (Allcott and Keniston, 2014). Moreover, to the extent that increasing income of households involved in fracking oil production improves the health of the local economies, it might benefit consumer-oriented industries that experience an increasing demand for their goods, i.e. the “income effect hypothesis” (Acemoglu et al. 2013; Cascio and Narayan, 2015). Finally, to the extent that good news about fracking oil supply can depress oil prices, it may benefit a variety of industries whose output consists of goods that are complements with oil (e.g., cars) or whose expenditure shares increase through the effect on the consumers’ budget constraints, i.e. the “price effect” hypothesis. Given the substantial drilling activities in the state of Oklahoma that may activate all the above discussed effects on the workings of the local economy, along with the potential hazardous effects on the quality of the local environment, the goal of this paper is to empirically explore, for the first time, the impact of fracking activities on the state’s housing prices which are a significant component of the State’s economy. The motivation is quite obvious: we are especially concerned about potential negative effects from fracking that could adversely affect property values and increase mortgage defaults. At the same time, positive effects might be expecting through the impact on employment and production levels (Foote et al., 2008). Overall, the net effect of fracking on housing prices is uncertain and, ultimately, an empirical question. The findings are expected to have important implications for land owners, as well as policymakers and energy regulators towards state and national energy and housing policies.

According to Gade et al. (2017), a certain strand of the literature has explored the impact of oil and gas developments on regional economic outcomes, such as unemployment, with the empirical findings providing mixed results (Lee 2015; Munasib and Rickman 2015; Weinstein 2014; Weber, 2014, 2012; Michaels, 2010). This paper builds on the existing literature by examining whether and how fracking drilling activities have affected housing prices across Oklahoma’s counties. The paper makes certain contributions to the literature: first, to the best of our knowledge, this study is the first to examine the effect of fracking on Oklahoma’s housing prices; next, it explicitly splits the baseline sample into the period prior and after the fracking boom occurred in 2006 (the break event is endogenously determined) to disentangle any potential differentiated behavior of housing prices across the two regimes. To foreshadow the empirical findings, they document that fracking has exerted a positive impact on such prices, which, however, turns out to be statistically significant only after the boom of the fracking technology. Finally, considering certain geographical characteristics, the analysis provides robust results.

The paper proceeds in the following manner. Section 2 discusses the economic effects of fracking with emphasis on housing prices, while Section 3 discusses methodological issues. Section 4 presents the data used, while Section 5 documents the baseline and robustness findings. Finally, Section 6 concludes.

2. Economic Effects of Fracking and the Related Literature

2.1. An overview of the fracking process

Horizontal drilling combined with hydraulic fracturing technology allows producers to develop deposits of oil and natural gas that are trapped in deep shale and tight sands formations often one mile below the surface. To access the resources, producers drill vertically until they reach the reservoir, the kickoff point, and then the wellbore starts curving horizontally. These technological developments in well drilling consist of pumping a mixture of water, sand and chemicals under controlled conditions into deep underground shale or tight sands formations. The injected sand and fluid remain in the rock to leave cracks open so that when the pump pressure is released, the oil or natural gas can flow into the horizontal casing and then up to the wellbore (American Petroleum Institute, 2009). In the US, local responses have varied widely. More specifically, such unconventional oil and natural gas developments continue full speed ahead in certain states and regions, while others have halted it temporarily, or even banned it. The discussion is heated up because such unconventional oil and gas operations require water. The amount and quality needed varies greatly from location to location. Some operations require substantial quantities of water. Operators could use saltwater and wastewater rather than freshwater for hydraulic fracturing. However, more safeguards must be in place to handle contaminants in the latter (Burton et al., 2014; Field et al., 2014; Allen, 2014).

2.2. Economic and other implications of fracking

A new strand of the literature also quantifies the impact of fracking on housing values, which can incorporate a wide range of amenities and disamenities. As fracking moved into the counties in the relevant states it has created concerns by homeowners about environmental effects and reduced housing values. By contrast, the increase in drilling activity could result in gains in employment and increased the demand for housing. Using data on housing transactions, Gopalakrishnan and Klaiber (2012) and

James and James (2014) find that proximity to a shale gas well reduces housing values. Delgado et al. (2014) also find weak evidence of this, and Muehlenbachs et al. (2015) find this to be the case for properties that use private groundwater wells. At a broader level, both positive and negative impacts have been found. In particular, Weber et al. (2014) find Texas housing values are higher in zip codes with shale, hypothesized to be driven by local public finances, while Boslett et al. (2014) provide evidence that properties in New York would have gained value had New York not imposed a moratorium on hydraulic fracturing. In a very recent work, Muehlenbachs et al. (2015) find that there are increases in housing values in Pennsylvania when shale gas wells are drilled in the general vicinity of a house; however, this is only in the first year that wells are drilled. Furthermore, wells that were permitted, but have remained undrilled have a negative impact, which increases with the length of time since permitting.

Hydraulic fracturing produces wastewater of highly varying quality and quantity, depending on the process used and geological conditions. These waters may be highly saline and contain radioactive materials, toxic heavy metals, and other natural and industrial materials. The handling, treatment, and final disposition of this wastewater need better oversight. In addition, these unconventional oil and natural gas operations can pose risks to groundwater. While typically low, these risks include cross-aquifer contamination, seepage of surface contaminants, and leaks and spills from improperly cemented well casings (Warner et al., 2013; Vengosh et al., 2014). Unconventional oil and natural gas developments follow a boom-and-bust cycle that is typical of extractive industries, with this cycle being often linked with workforce diversion, abandoned facilities, and increases in local crime. In addition, rapid unconventional oil and natural gas developments generate social disruptions and a greater likelihood of accidents from truck traffic, while hazardous air pollutants from fracking operations, such as benzene, ozone, and particulates, can produce negative short- and long-term health effects. Well developments can increase exposure to pollutants across residents closest to the well pad, undermining their health, while contamination of domestic water supplies also poses public health risks (Stamford and Azapagic, 2014). Finally, workers in the industry face risks from exposure to silica in the fracking sand. Silica causes silicosis, a serious progressive lung disease. Such exposure can occur during transport of the sand as well as at drilling sites. Overall, a lack of baseline and long-term monitoring and comprehensive health assessments hamper efforts to fully assess and mitigate these health risks (Kovats et al., 2014).

With the surge in fracking drilling, oil and gas production in the US has increased dramatically over the last decade. The substantial increase in natural gas production over the same time period has induced clear benefits to consumers. Because supply has increased and the equilibrium price of gas has fallen, consumer surplus is doubly enhanced. To be sure, the increased supply lowers home heating costs during the winter, but it induces year-long benefits. As its cost falls, natural gas has become an increasingly important fuel for electricity generation, which lowers costs to gas-fired electricity producers, as well as electricity prices for consumers (Linn et al., 2014). Moreover, the expanded supply of natural gas, and attendant reduction in prices, have facilitated its role as an input into a variety of industrial production processes, which generates far-reaching economic benefits (US Energy Information Administration 2014). In addition to benefiting consumers, the widespread adoption of fracking has generated gains to producers, particularly, via the finding of more reserves. A resource boom can result in increased investment in the non-extraction sectors. By contrast, a resource boom can increase all local prices, contracting the tradable, non-resource sectors. Empirical research has found evidence of both positive and negative impacts from oil and gas booms. Marchand (2012) does not find any significant changes in employment in the case of Western Canada, while Allcott and Keniston (2014) find that manufacturing growth is higher in resource-abundant counties, implying agglomeration is a more important factor.

2.3. Research in relevance to Oklahoma

A strand of the literature has attempted to explore the impact of some new factors on housing prices in Oklahoma. Our study is close to this particular strand, but offers more extended and different findings by considering data across all Oklahoma's counties and not just focusing limited county regions. Liu et al. (2016) use data from Oklahoma County, an area severely affected by the increased seismicity and provide hedonic estimates of property value impacts from shale oil and gas development that vary with earthquake risk exposure. Their results document that the 2011 Oklahoma earthquakes in a single country have enhanced the perception of risks associated with wastewater injection. This study differs in the sense that it covers all counties within a panel series framework. In addition, Cheung et al. (2016) examine the impact of earthquakes on residential property values using sales data from Oklahoma from 2006 to 2014. While before 2010, Oklahoma had only a couple of earthquakes per year that were strong enough to be felt by residents, since 2010, seismic activity has increased. They estimate that prices declined after a home has experienced earthquakes. Their results are consistent with the experience of an earthquake revealing new risks that are then could be capitalized into house values. Finally, within a similar framework, Metz et al. (2017) investigate how seismic activity in Oklahoma has impacted the costs of home prices. Their findings illustrate a negative effect on property values. However, they focused only on a single year, while our study has considered a longer time span, with our results recommending a positive effect on property values.

3. Methodology

The empirical analysis is focused on measuring the influence of the number of drilling (fracking) oil and natural gas wells on housing prices. Based on theoretical modeling arguments where the dynamics of housing prices are driven by the evolution of its demand and its interaction with the supply of housing, we can really identify a number of potential housing prices determinants. Our approach accounts for certain housing fundamentals, which determine the long-run demand and supply relationships. This approach is based on the basic premise introduced by Poterba's (1984) asset market approach in order to explain the functioning of this market in the short run. More specifically, he considers the quantity demanded for housing services as a function of the real rent price of those services, and the stock of houses, which is given in the short run. The literature on housing prices is part of the general theoretical approach that attempts to identify the determinants of house prices through supply factors, such as the availability of land and construction activities, and through demand factors, such as interest rates, inflation, wages or income, mortgage loans and the population (Hofmann, 2004; Tsatsaronis and Zhu, 2004; Goodhart and Hofmann, 2008; Stepanyan, 2010; (Sweeney-Bindels, 2011; Myrmo, 2012; Xu and Tang, 2014), with the demand for and supply of housing being heterogeneous and differing across countries, counties and cities.

Therefore, the price of the housing services in equilibrium is the one, which balances the desired quantity of housing services with the service flow, which exists in the market at that point. Muellbauer and Murphy (1997) also follow this approach and represent the dynamics in the housing market by means of an equation of demand for housing service, which depends mainly on average real income, which captures housing prices; and a supply of housing services function, which rely on housing prices and the population size. In this framework, the housing price equation can be considered as an inverted demand function. All these basic premises are still valid and constitute the foundations of recent theoretical developments like, for example, Miles (2012). Based on the above framework of discussion, our modelling approach falls within the supply and demand framework, which is the framework that avoids considering ad hoc drivers that determine housing prices, and, thus, the main specification of the fixed effects model yields:

$$hp_{it} = a_{1i} + \beta_1\, dw_{it} + \beta_2\, y_{it} + \beta_3\, pop_{it} + \beta_4\, D_{crisis} + \varepsilon_{it} \qquad (1)$$

where, hp represents county’s real housing prices, dw represents the annual county drilling activity, y is county’s real personal income, pop is the county-year population, D_{met} is a dummy variable denoting whether the county is metro or non-metro (taking one if the county is metro, and zero otherwise), D_{pr} is.a dummy variable denoting whether the county is consistent (i.e., a producer throughout the entire time span under study) oil and gas producing county (taking one of this holds, and zero otherwise), and finally, D_{crisis} is a dummy variable that explicitly considers the recent global financial crisis in 2008 (taking 1 at 2008, and zero otherwise). a_{1i} represents county fixed effects, while □ is the error term. To address concerns over local economic factors, the analysis controls for dynamic changes in personal income and county population. Finally, within the demand and supply framework considered by model (1), the primary variable of drilling activity is characterized as a supply factor and can be explicitly and formally inserted in our modelling approach in order to assess its impact on housing prices. Based on the framework of model (1), we can apply long-run estimation methods and explore the statistical significance, as well as the sign role of the primary control driver which is that of drilling activities.

The empirical analysis applies a panel methodology which takes into account cross-section and time dimensions of the data, as well as cross dependence, to estimate the long run relationship described in Equation (1). When the errors of a panel regression are cross-sectionally correlated then standard estimation methods can lead to inconsistent estimates and incorrect inference (Phillips and Sul, 2003). In order to consider the cross-sectional dependence, we implement a novel econometric methodology, namely, the Common Correlated Effects (CCE) by Pesaran (2006). He suggests a new approach to estimation that takes into account cross sectional dependence. The proposed methodology allows individual specific errors to be serially correlated and heteroskedastic. Pesaran (2006) adopts a multifactor residual model, such as:

$$hp_{it} = a_{1i} + \beta_1 dw_{it} + \beta_2 y_{it} + \beta_3 pop_{it} + \beta_4 D_{crisis} + \varepsilon_{it}$$

$$\varepsilon_{it} = \lambda'_i F_t + u_{it} \qquad (2)$$

where subscript *it* is the ith cross section observation at time *t*, for $t=1,2,\ldots,T$ and i ¿ $1,2,\ldots,N$. F_t is the mx1 vector of unobserved common factors. Pesaran (2006) considers the case of weakly stationary factors. However, Kapetanios et al. (2011) show that Pesaran's CCE approach continues to yield consistent estimation and valid inference even when common factors are unit root processes (I(1)). To deal with the residual cross section dependence Pesaran (2006) uses cross sectional averages, as observable proxies for common factors F_t. Slope coefficients as well as their means, can be consistently estimated within the following auxiliary regression:

$$hp_{it} = a_i + \beta_1 wd_{it} + \beta_2 y_{it} + \beta_3 pop_{it} + \beta_4 D_{crisis} + a_1 \overline{hp}_t + a_2 \overline{wd}_t + a_3 \overline{y}_t + a_4 \overline{pop}_t + \varepsilon_{it} \qquad (3)$$

Pesaran (2006) refers to the resulting OLS estimators $\hat{B}_{j,CCE}$ of the individual specific slope coefficients $B_j = (\beta)'$, as the 'Common Correlated Effect' (CCE) estimators:

$$\hat{B}_{j,CCE} = \left(X_j' \acute{D} X_j\right) X_j' \acute{D} E_j,$$

where: $X_j = \left(x_{j1}, x_{j2}, \ldots, x_{jT}\right)'$, $x_{jt} = \left(Y_{jt}, Y_{jT}^2\right)'$, $E_j = \left(E_{j1}, E_{j2}, \ldots, E_{jT}\right)'$, $\acute{D} = I_T - \acute{H}\left(\acute{H}'\acute{H}\right)^{-1}\acute{H}$, $\acute{H} = \left(h_1, h_2, \ldots, h_T\right)'$, and

$h_t = (1, hp_t, wd_t, y_t, pop_t,)$ as the 'Common Correlated Effect' (CCE) estimators. The 'Common Correlated Effects Mean Group' (CCEMG) estimator is the average of the individual CCE estimators $\hat{B}_{j,CCE}$:

$$\hat{B}_{CCEMG} = \sum_{j=1}^{N} \hat{B}_{j,CCE} .$$

The new CCEMG estimator follows asymptotically the standard normal distribution. Specifically:

$$\sqrt{N}\left(\hat{B}_{CCEMG} - B\right) \vec{d}\, N\left(0, \Sigma_{MG}\right) . \quad (4)$$

In a series of Monte Carlo experiments, Pesaran (2006) and Kapetanios et al. (2011) show that the CCE estimators have the correct size, and in general have better small-sample properties than alternatives that are available in the literature. Furthermore, they have shown that small-sample properties of the CCE estimators do not seem to be much affected by the residual serial correlation of the errors.

4. Data

To the end of the empirical analysis, the number of drilled oil and natural gas wells serves as our measure of oil and gas development. The measure provides a complete set of oil and gas drilling activity. The drilling wells data for the analysis are collected from the relevant state oil and gas and or geologic agency, i.e. The Oil and Gas Division of The Oklahoma Corporation Commission. Data are collected, spanning the period 2000-2015, totaling 1,216 observations (16 years x 76 counties).

In terms of housing prices, data on average housing price transactions provided by Corelogic are obtained. In addition to those index data, associated information on whether the house is groundwater-dependent was also provided. Finally, population comes as total county residents according to the 2012 census estimates. In terms of the county income measure, data come as households' income from each county. Data on population and personal income at the county level are obtained from the Bureau of Economic Analysis (BEA). All data come on an annual basis, and they were turned into logarithmic values, essentially denoting elasticity (percentage) terms. Table 1 in the Appendix reports a number of descriptive statistics (all on their actual levels), while Figure 1 illustrates the course of Oklahoma State's housing prices over the sample under study.

[Insert Table 1 about here]

[Insert figure 1 about here]

5. Empirical Analysis

We employ panel cointegration to investigate the long-run equilibrium across the variables under study. The study makes use of the Durbin-Hausman test, recommended by Westerlund (2008), to explore the presence of cointegration. In particular, this test is applied under very general conditions because it does not rely heavily on a priori knowledge of the integration order of the variables included in the modelling approach. Additionally, it allows for cross-sectional dependence modelled by a factor model in which the errors in equation (1), ε_{it}, are obtained by idiosyncratic innovations and unobservable factors that are common across units of the panel (Auteri and Constantini, 2005). Two panel cointegration tests are employed: the panel test (DH_g) and the group mean test (DH_p). The tests have different probability limits under the cointegration alternative hypothesis, while sharing the property of consistency under the no co-integration null hypothesis.

The results of the DH_g and DH_p tests are reported in Table 2. The findings clearly illustrate that the null hypothesis of no-cointegration is rejected at the 1% significance level for both tests, indicating that there exists a significant long-run equilibrium among housing prices, fracking drilling wells, real income and county population in our countries sample.

[Insert Table 2 about here]

Next, Table 3 reports the results of unit root tests. In particular, two second-generation panel unit root tests are employed to determine the degree of integration in the variables under investigation. The Pesaran (2007) panel unit root test in which the null hypothesis is a unit root and the bootstrap panel unit root tests by Smith et al. (2004). Both tests by Smith et al. (2004) are constructed with a unit root under the null hypothesis. The results of these panel unit root tests support the presence of a unit root across all variables under consideration.

[Insert Table 3 about here]

The results are reported in Table 4. The findings highlight a positive and statistically significant housing price effect, indicating that adding more drilling wells leads to a 6.9 percent increase in housing prices. Both county population and income exert a positive and statistically significant effect on housing prices, indicating that the increased drilling activity has a positive effect on property values despite the potential effect of any seismic activity. In terms of the crisis variable, the impact on housing prices in Oklahoma is negative and statistically significant.

[Insert Table 4 about here]

The next stage of the empirical analysis estimates the presence of break(s) and its(their) location through the Bai and Perron (2003) methodological approach. These findings are reported in Table 5. From those results we can notice that housing prices in Oklahoma counties have been subject to the presence of a break. It is more than apparent that clustering of the break date around 2006 occurs, while it remains strongly robust across counties. More specifically, the findings identify one major break change associated with technological developments in fracking occurred in 2006, while this break date is synchronized across Oklahoma's counties.

[Insert Table 5 about here]

Given that the break date test identified the year 2006 as a break event, the next step of the empirical analysis carries on the analysis by first investigating the presence of cointegration across the two regimes (i.e., prior and after the 2006 break event). Once again, Westerlund (2008) cointegration results, reported in Table 6, display that over both regimes the statistics reject the null of no cointegration at the 1% significance level and confirm that there is a long-run relationship between housing prices and the remaining drivers in equation (1).

[Insert Table 6 about here]

Given the presence of cointegration across both regimes, we next obtain the long-run estimates using once again the Common Correlated Effects (CCE) approach. The new results are reported in Table 7, with the findings providing evidence that prior to 2006 fracking is exerting a positive, albeit statistically insignificant, impact on housing prices, while over the period after the 2006 fracking boom, the coefficient turns out to be statistically significant, indicating the potentially higher technological efficiency of fracking developments. The remaining variables retain their sign and statistical significance across both regimes.

[Insert Table 7 about here]

This sub-section extends the baseline results by considering the distance of houses from the drilling wells. In Oklahoma you cannot build a home near a well, but drilling a well next to a home is perfectly legal. The distances have been determined through the Resource for the Future's Center for Energy Economics and Policy that uses Geographic Information System (GIS) technology. Thus, we divide the drilling wells that are within 1km, 5km, 10km and 20km from properties and those outside those distances. In that sense, we introduce a dummy variable (at a time), $D_{distance}$, that takes 1 if the distance between the drilling well and the house is within 1km, 5km, 10km or 20km, and 0 otherwise. In addition, a new dummy variable is introduced, D_{water}, that considers whether the house is groundwater-dependent. Hence, this dummy variable takes the value of 1 if the house is ground water-dependent, and 0 otherwise. The new model to be estimated yields:

$$hp_{it} = a_i + \beta_1 dw_{it} + \beta_2 y_{it} + \beta_3 pop_{it} + \beta_4 D_{crisis} + \beta_5 D_{distance} + \beta_8 D_{water} + \varepsilon_{it} \quad (5)$$

First, the new results of the DH_g and DH_p tests are reported in Table 8. These new findings highlight again that the null hypothesis of no-cointegration is rejected at the 1% significance level for both tests, indicating that there exists a significant long-run equilibrium among housing prices and the new set of control variables in equation (5).

[Insert Table 8 about here]

Finally, Table 9 reports the estimates of the new model described in equation (5) across various distances from wells. The new findings clearly document again the positive effect of fracking drilling wells on housing prices, with the distance dummy exerting a declining impact as we are moving away from wells, while the estimates remain statistically significant at 5%. The remaining control variables have retained their explanatory size and significance. The groundwater-dependent dummy also exerts a negative effect on housing prices. The overall of explanatory power of the model has also increased, as this is indicated from a larger adjusted R^2, though the adjusted R^2 moves declining as we are moving away from drilling wells.

[Insert Table 9 about here]

6. Conclusion and Policy Implications

Development of fracking has become increasingly widespread due to advances in technology across a number of U.S. states. These technological developments allow for the inexpensive enhanced extraction of oil and natural gas. However, they have also generated strong debate on whether the benefits from more fuels and the accompanying economic development could be outweighed by the negative impact associated with the extraction technology. Overall, the enhanced extraction has abruptly lowered energy prices, strengthened energy security and even lowered air pollution and carbon dioxide emissions by displacing coal in electricity generation. These lower energy prices have meant more money in the pockets of American families and businesses, while lower emissions are certainly good news for our health with large reductions in air pollution dispersed across the country and, at least for the planet's climate. Lower energy prices also mean lower unemployment and interest rates, thus, more investment volumes and definitely a higher demand for housing near the fracking regions and, thus, higher housing prices. By contrast, it could bring more truck traffic, increases in crime and potential health impacts, possibly due to air and/or water pollution.

This study provided empirical evidence on this debate for the case of Oklahoma's State housing prices. The provided evidence has extensive merit, given the earthquake sequence over the last few years and the fact that the media has been placing on this risk for potential negative impact on housing values. Given that fracking technologies can also bring a positive impact to state counties through increased employment opportunities and a further economic expansion, the empirical findings of this study also provided supportive evidence that there were positive effects on housing values (despite a recent rising earthquake activity).

Despite the positive findings, however, there is ample discussion focusing on three main areas: the role of federal, state, and local governments in regulating hydraulic fracturing, the scope and specificity of efficient regulation, and the aspects of hydraulic fracturing that require regulation. The regions considering and already facing unconventional oil and natural gas developments can create regulations that encourage oil and natural gas industries to implement the best practices and drive innovation in the energy sector. The exploding scale and intensity of fracking operations can lead to loopholes, inconsistencies, and inadequacies in the regulatory structure at all levels of the governments. State governments are in the best position to regulate the industry, given their expertise and capacity. The federal government could also help standardize protocols, devices, and standards for measuring the impacts of the industry.

Given that a lot of people are concerned about the public health effects of fracking, i.e. from air and water pollution, the lack of data available on these factors may be downplaying some of the perceived risks associated with fracking that were hypothesized would be capitalized into housing values. An extension of such research venue could provide more valuable information on the role of fracking in determining housing prices in Oklahoma. Since health is such a critical factor, future research venues should dig in further by looking at the health of those born near fracking sites.

References

Acemoglu, D., Finkelstein, A., Notowidigdo, M.J. 2013. Income and health spending: evidence from oil price shocks. The Review of Economics and Statistics 95, 1079-1095.

Albuquerque, R., Eichenbaum, M.S., Rebelo, S. 2015. Valuation risk and asset pricing. Journal of Finance 71, 2861-2904.

Allcott, H., Keniston, D. 2014. Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America. Working Paper, No. 20508, NBER.

Allen, D.T. 2014. Atmospheric emissions and air quality impacts from natural gas production and use. Annual Review of Chemical Biomolecule Engineering 5, 55-75.

American Petroleum Institute. 2009. Hydraulic fracturing operations, well construction and integrity guidelines. API Guidance document HF1.

Auteri, M., Constantini, M. 2005. Intratemporal substitution and government spending: unit root and cointegration tests in a cross section correlated panel. 17th Conference Paper, Societa Italiana di economia pubblica, Pavia, Universita.

Bai, J., Perron, P. 2003. Computation and analysis of multiple structural change models. Journal of Applied Econometrics 18, 1-22.

Baker, S.R., Bloom, N., Davis, S.J. 2015. What triggers stock market jumps? Technical Report, Working Paper.

Bansal, R., Kiku, D., Shaliastovich, I., Yaron, A, 2014. Volatility, the macroeconomy, and asset prices. The Journal of Finance 69, 2471-2511.

Boslett, A., Guilfoos, T., Lang, C. 2014. Valuation of expectations: a hedonic study of shale gas development, a statewide moratorium, and local resolutions. Unpublished Manuscript.

Burton, G.A., Basu, N., Ellis, B.R. 2014. Hydraulic “fracking”: are resurface water impacts an ecological concern? Environmental Toxicological Chemistry 33, 1679-1689.

Campbell, J.Y., Giglio, S., Polk, C., Turley, R. 2016. An intertemporal CAPM with stochastic volatility. Technical Report, National Bureau of Economic Research.

Cascio, E.U., Narayan, A. 2015. Who needs a fracking education? The educational response to low-skill biased technological change. Working Paper, No. 21359, National Bureau of Economic Research.

Cheung, R., Wetherell, D., Whitaker, S. 2016. Earthquakes and house prices: evidence from Oklahoma. Working Paper, No. 16-31, Federal Reserve Bank of Cleveland.

Cochrane, J.H. 2011. Presidential address: discount rates. The Journal of Finance 66, 1047-1108.

Delgado, M.S., Guilfoos, T., Boslett, A. 2014. The cost of hydraulic fracturing: a hedonic analysis. Unpublished Manuscript.

Feyrer, J., Mansur, E.T., Sacerdote, B. 2017. Geographic dispersion of economic shocks: evidence from the fracking revolution. American Economic Review 107, 1313-1334.

Field, R.A., Soltis, J., Murphy, S. 2014. Air quality concerns of unconventional oil and natural gas production. Environmental Science Process Impacts 16, 954-969.

Foote, C.L., Gerardi, K., Willen, P.S. 2008. Negative equity and foreclosure: theory and evidence. Journal of Urban Economics 64, 234-245.

Gade, M.N., Maguire, K., Makamu, F. 2017. Oklahoma oil and gas severance taxes: a comparative analysis. Working Paper, No. 17-01, Oklahoma State University.

Goodhart, C., Hofmann, B. 2008. House prices, money, credit, and the macroeconomy. Oxford Review of Economic Policy 24, 180-205.

Gopalakrishnan, S., Klaiber, H.A. 2014. Is the shale energy boom a bust for nearby residents? Evidence from housing values in Pennsylvania. American Journal of Agricultural Economics 96, 43-66.

Greenwald, D.L, Lettau, M., Ludvigson, S.C. 2014. The origins of stock market fluctuations. Working Paper, National Bureau of Economic Research.

Greenwood, R., Shleifer, A. 2014. Expectations of returns and expected returns. Review of Financial Studies 27, 714-746.

Hausman, C., Kellogg, R. 2015. Welfare and distributional implications of shale gas. Brookings Papers on Economic Activity 73, 1-45.

Hofmann, B. 2004. Bank lending and property prices: some international evidence. Working Paper, No 222003, Hong Kong Institute for Monetary Research.

James, A., James, J. 2014. A canary near a gas well: gas booms and housing market busts in Colorado. Unpublished Manuscript.

Kapetanios, G., Pesaran, M.H., Yamagata, T. 2011. Panels with non-stationary multifactor error structures. Journal of Econometrics 160, 326-348.

Kovats, S., Depledge, M., Haines, A. 2014. The health implications of fracking. The Lancet 383, 757-758.

Lamont, O., Frazzini, A. 2007. The earnings announcement premium and trading volume. Working Paper, No. 13090, National Bureau of Economic Research.

Lee, J. 2015. The regional economic impact of oil and gas extraction in Texas. Energy Policy 87, 60-71.

Linn, J., Muehlenbachs, L., Wang, Y. 2014. How do low natural gas prices affect electricity consumers and the environment? Working Paper, Resources for the Future, Washington DC.

Liu, H., Ferreira, S., Brewer, B. 2016. The housing market impacts of wastewater injection induced seismicity risk. Paper presented at the Agricultural and Applied Economics Association meetings, Boston.

Lucca, D.O., Moench, E. 2015. The pre-FOMC announcement drift. The Journal of Finance 70, 329-371.

Marchand, J. 2012. Local labor market impacts of energy boom-bust-boom in Western Canada. Journal of Urban Economics 71, 165-174.

Metz, N.E., Roach, T., William, J.A. 2017. The costs of induced seismicity: a hedonic analysis. Economics Letters 160, 86-90.

Miles, D. 2012. Demographics, house prices and mortgage design. Bank of England External MPC Discussion Paper, No. 35, London: Bank of England.

Muehlenbachs, L., Spiller, E., Timmins, C. 2015. The housing market impacts of shale gas development. American Economic Review 105, 3633-3659

Muellbauer, J., Murphy, A. 1997. Booms and busts in the UK housing market. The Economic Journal 107, 1701-1727.

Munasib, A., Rickman, D. 2015. Regional economic impacts of the shale gas and tight oil boom: a synthetic control analysis. Regional Science and Urban Economics 50, 1-17.

Myrmo, M. 2012. Does population growth affect housing bubbles? A study on population growth's influence on the U.S. housing market during the 2000's. Working Paper, Bergen: Norwegian School of Economics.

Newey, W.K., West, K.D. 1994. Automatic lag selection in covariance matrix estimation. Review of Economic Studies 61, 631-653.

Pesaran, M.H. 2007. A simple panel unit root test in the presence of cross-section dependence. Journal of Applied Econometrics 22, 265-312.

Pesaran, M.H. 2006. Estimation and inference in large heterogeneous panels with a multifactor error structure. Econometrica, 74 967-1012.

Phillips, P.C.B., Sul, D. 2003. Dynamic panel estimation and homogeneity testing under cross section dependence. The Econometrics Journal 6, 217-259.

Poterba, J.M. 1984. Tax subsidies to owner-occupied housing: an asset-market approach. The Quarterly Journal of Economics 99, 729-752.

Savor, P.G., Wilson, M.I., 2013. How much do investors care about macroeconomic risk? Evidence from scheduled economic announcements. Journal of Financial and Quantitative Analysis, 48, 343-375.

Savor, P.G., Wilson, M.I. 2015. Earnings announcements and systematic risk. The Journal of Finance 71, 83-138.

Skoumal, R.J., Brudzinski, M.R., Currie, B.S. 2015. Earthquakes induced by hydraulic fracturing in Poland Township, Ohio. Bulletin of Seismology Society of America 105, 189-197.

Smith, V., Leybourne, S., Kim, T.H., Newbold, P. 2004. More powerful panel unit root tests with an application to the mean reversion in real exchange rates. Journal of Applied Econometrics 19, 147-170.

Stamford, L., Azapagic, A. 2014. Life cycle environmental impacts of UK shale gas. Applied Energy 134, 506-518.

Stepanyan, V., Poghosyan, T., Bibolov, A. 2010. House price determinants in selected countries of the former Soviet Union. IMF Working Paper.

Sweeney-Bindels, E 2011. Housing policy and delivery in Namibia. Working Paper, Institute for Public Policy Research.

Tsatsaronis, K., Zhu, H. 2004. What drives housing price dynamics: cross country evidence. Working Paper, BIS Quarterly Review.

US Energy Information Administration. 2014. Annual energy outlook 2014, with projections to 2040. EIA. Rep. US Energy Information Administration, Washington, DC.

Vengosh, A., Jackson, R.B., Warner, N., Darrah, T.H., Kondash, A. 2014. A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. Environmental Science of Technology 48, 8334-8348.

Warner, N.R., Christie, C.A., Jackson, R.B., Vengosh, A. 2013. Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. Environmental Science of Technology 47, 11849-11857.

Weber, J.G. 2014. A decade of natural gas development: the makings of a resource curse? Resource and Energy Economics 37, 168-183.

Weber, J.G. 2011. The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. Energy Economics 34, 1580-1588.

Weber, J.G., Burnett, J., Xiarchos, I.M. 2014. Shale gas development and housing values over a decade: evidence from the Barnett shale. Working Paper, No. 14-165, US Association of Energy Economics, Cleveland, OH.

Weinstein, A.L. 2014. Unconventional oil and gas development's impact on state and local economies. Choices 29, 1-7.

Westerlund, J. 2008. Panel cointegration tests of the Fisher effect. Journal of Applied Econometrics 23, 193-233.

Xu, L., Tang, B. 2014. On the determinants of UK house prices. International Journal of Economic Research 5, 57-64.

Table 1
Descriptive statistics.

Variable	Mean	S.D.
Housing prices	$166,750	538,772
Income	$43,748	562,702
Population	65,796	214,653
Drilling wells	4,681	743.39
Observations: 1,216		

Table 2

Westerlund's panel cointegration tests.

DH_g	$7.852[0.00]^{***}$
DH_p	$9.306[0.00]^{***}$

p-values are reported in brackets. The criterion used in this paper is $IC_2(K)$ with the Maximum number of factors (K) set equal to 5. For the bandwidth selection, M was chosen to represent the largest integer less than $4(T/100)^{2/9}$, as suggested by Newey and West (1994). ***: $p \leq 0.01$ and indicates the rejection of no co-integration null hypothesis.

Table 3

Panel unit root tests.

Variable	Pesaran CIPS	Smith et al. t-test	Smith et al. LM-test
Hp	-1.14	-1.39	3.35
Δhp	-5.49***	-6.92***	19.80***
Dw	-1.23	-1.35	3.15
Δdw	-5.68***	-6.62***	21.39***
Y	-1.30	-1.39	3.09
Δy	-5.74***	-6.48***	25.48***
pop	-1.36	-1.38	2.94
Δpop	-5.58***	-6.17***	25.93***

Δ = first differences. Rejection of the null hypothesis indicates stationarity. ***: $p \leq 0.01$.

Table 4

Common correlated effects mean group (CCE-MG) estimates.

variables	coefficient	t-statistics	p-values
constant	1.583	3.819	0.01
drilling wells	0.069	7.782	0.00
income	0.049	5.883	0.00
population	0.044	6.338	0.00
crisis dummy	-0.616	-7.549	0.00
Adjusted R-squared	0.68		

Table 5

Estimated break(s) for housing prices.

State	UD_{max}	WD_{max}	Break location
Alfalfa	25.42***	31.27***	2006
Aloka	23.97***	28.75***	2006
Beaver	27.09***	32.57***	2006
Beckham	26.48***	29.16***	2006
Blaine	29.07***	34.52***	2006
Bryan	26.31***	29.84***	2006
Caddo	25.63***	28.99***	2006
Canadian	24.09***	27.55***	2006
Carter	27.69***	30.36***	2006
Cherokee	26.84***	29.71***	2006
Choctaw	28.62***	32.10***	2006
Cimarron	27.39***	30.80***	2006

Cleveland	24.39***	28.71***	2006
Coal	26.19***	29.06***	2006
Comanche	18.42***	23.19***	2006
Cotton	21.36***	25.14***	2006
Craig	13.09**	18.92***	2006
Creek	23.19***	27.41***	2006
Custer	25.40***	29.15***	2006
Delaware	10.85**	14.31**	2006
Dewey	24.59***	28.71***	2006
Ellies	20.52***	24.93***	2006

Table 5 *Continued*

Garfield	21.52***	24.38***	2006
Garvin	17.63***	22.08***	2006
Grady	25.40***	29.63***	2006
Grant	23.48***	26.51***	2006
Greer	19.04***	24.37***	2006
Harmon	22.38***	26.50***	2006
Harper	11.09**	13.29**	2006
Haskell	20.18***	24.37***	2006
Hughes	24.31***	27.82***	2006
Jackson	19.88***	23.36***	2006
Jefferson	10.65**	15.40**	2006
Johnston	16.52***	20.12***	2006
Kay	21.39***	24.51***	2006
Kingfisher	23.10***	26.59***	2006
Kiowa	21.18***	24.39***	2006

Latimer	18.76***	21.58***	2006
Le Flore	16.59***	19.04***	2006
Lincoln	24.39***	27.91***	2006
Logan	23.09***	27.16***	2006
Love	26.59***	30.18***	2006
Major	21.08***	24.39***	2006
Marshall	19.06***	23.16***	2006
Mayes	26.52***	29.35***	2006
McClain	12.35**	16.59***	2006
McCurtain	20.29***	24.72***	2006

Table 5 *Continued*

McIntosh	23.28***	27.81***	2006
Murray	19.84***	22.09***	2006
Muskogee	21.44***	25.61***	2006
Noble	27.94***	31.39***	2006
Nowata	23.18***	26.59***	2006
Okfuskee	18.77***	22.19***	2006
Oklahoma	28.91***	33.48***	2006
Okmulgee	23.41***	26.53***	2006
Osage	19.05***	22.55***	2006
Ottawa	14.51**	19.83***	2006
Pawnee	26.59***	29.04***	2006
Payne	23.44***	27.19***	2006
Pittsburg	16.51***	19.84***	2006
Pontotoc	19.48***	23.30***	2006
Pottawatomie	15.61**	18.94***	2006

Pushmataha	23.48***	27.92***	2006
Roger Mills	26.59***	29.39***	2006
Rogers	20.10***	24.37***	2006
Seminole	14.91**	18.73***	2006
Sequoyah	18.74***	21.94***	2006
Stephens	21.42***	25.30***	2006
Texas	26.55***	29.83***	2006
Tillman	19.06***	23.16***	2006
Tulsa	25.49***	28.16***	2006
Wagoner	18.73***	22.73***	2006

Table 5 *Continued*

Washington	15.81**	19.74***	2006
Washita	26.19***	28.05***	2006
Woods	24.13***	27.82***	2006
Woodward	20.91***	25.62***	2006

The breakpoint was estimated using the Bai and Perron (2003) procedure. UD_{max} and WD_{max} denote the Bai and Perron double maximum test statistics for the null hypothesis of no structural breaks versus the alternative of an unknown number of breaks. The reported WD_{max} corresponds to the 5% level of significance. ***: p≤0.01, **:p≤0.05.

Table 6

Westerlund’s panel cointegration results-prior and after the 2006 break point.

Prior the 2006 break event	
DH_g	6.985[0.00]***
DH_p	7.528[0.00]***
After the 2006 break event	
DH_g	6.562[0.00]***
DH_p	6.806[0.00]***

p-values are reported in brackets. The criterion used in this paper is $IC_2(K)$ with the Maximum number of factors (K) set equal to 5. For the bandwidth selection, M was chosen to represent the largest integer less than $4(T/100)^{2/9}$, as suggested by Newey and West (1994). ***: $p \leq 0.01$ and indicates the rejection of no co-integration null hypothesis at the 1% level of significance.

Table 7

CCE-MG estimates-prior and after the 2006 break point.

Variables	coefficient	t-statistics	p-values
Prior to the 2006 fracking boom			
constant	1.127	3.026	0.01
drilling wells	0.018	1.269	0.16
income	0.038	3.359	0.01
population	0.041	5.264	0.00
Adjusted R-squared	0.48		
After the 2006 fracking boom			
constant	1.792	5.062	0.00
drilling wells	0.093	9.329	0.00
income	0.065	5.127	0.00
populaion	0.060	6.569	0.00
Adjusted R-squared	0.77		

Table 8

Westerlund's panel cointegration results (the role of the distance from the well.

1 km	
DH_g	8.905[0.00]***
DH_p	10.685[0.00]***
5 km	
DH_g	8.126[0.00]***
DH_p	9.548[0.00]***
10 km	
DH_g	7.784[0.00]***
DH_p	9.109[0.00]***
20 km	
DH_g	8.076[0.00]***
DH_p	9.725[0.00]***

Similar to those in Table 3.

Table 9

CCE-MG estimates: the role of the distance from the well.

Variables	Coefficients			
	1km	**5km**	**10km**	**20km**
constant	1.239	1.016	1.079	1.0116
	[0.00]	[0.00]	[0.00]	[0.00]
drilling wells	0.046	0.041	0.038	0.032
	[0.02]	[0.02]	[0.03]	[0.03]
income	0.056	0.073	0.084	0.088
	[0.00]	[0.00]	[0.00]	[0.00]
population	0.047	0.045	0.047	0.042
	[0.00]	[0.00]	[0.00]	[0.00]
crisis dummy	-0.648	-0.639	-0.642	-0.648
	[0.00]	[0.00]	[0.00]	[0.00]

underground				
water dummy	-0.316	-0.308	-0.314	-0.320
	[0.00]	[0.00]	[0.00]	[0.00]
Adjusted R-squared	0.68	0.63	0.60	0.61

Figures in brackets denote p-values.

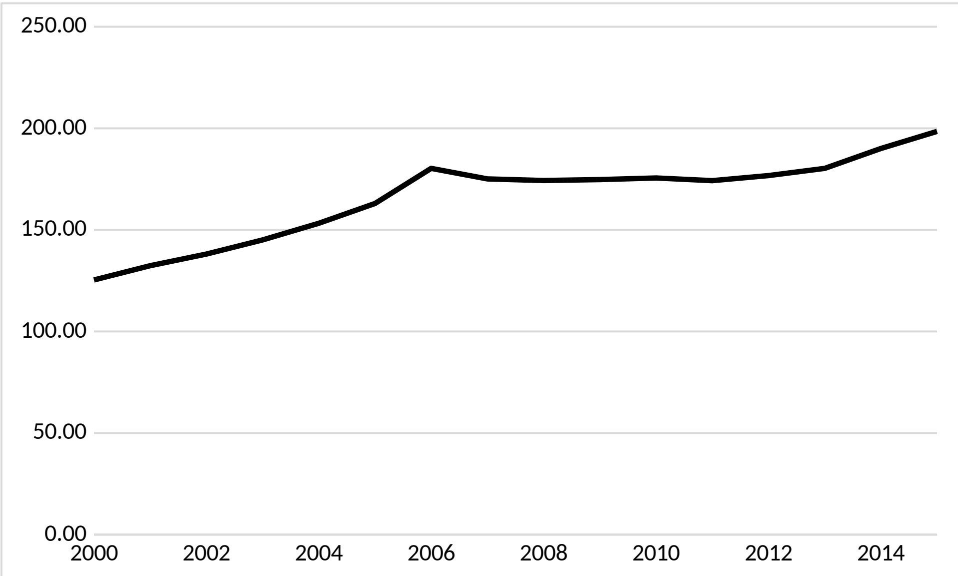

Fig. 1. Oklahoma State's housing prices, 2000-2015.